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Cost/benefit analysis of biomass energy supply options for rural smallholders in the semi-arid eastern part of Shinyanga Region in Tanzania

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ABSTRACT

This study analyzes the economic feasibility of sustainable smallholder bio-energy production under semi-arid conditions. The eastern part of Shinyanga region in Tanzania was chosen as a case study area. Three different sustainable biomass energy supply systems were compared by means of cost/benefit analysis: a small-scale forestation project for carbon sequestration, a short rotation woodlot and a Jatropha plantation, thereby using the produced Jatropha oil as a substitute for fuelwood or diesel. Rotational woodlots are most profitable with a Net Present Value of up to US$$_{2007}$ 1165/ha, a return on labour of up to US$$_{2007}$ 6.69/man-day and a fuelwood production cost of US$$_{2007}$ 0.53/GJ, compared to a local market price of US$$_{2007}$ 1.95/GJ. With a production cost of US$$_{2007}$ 19.60/GJ, Jatropha oil is too expensive to be used as an alternative for fuelwood. Instead it can be utilized economically as a diesel substitute, at an observed diesel cost of US$$_{2007}$ 1.49/l. The mean annual biomass increment (MAI) in semi-arid East Shinyanga is too low to collect sufficient benefits from trading forestation carbon credits under the Clean Development Mechanism (CDM) to cover the costs of forestation and forest management.

Contents

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1. Introduction

1.1. Problem definition

Traditional biomass is the main energy source in many developing countries. Its use is still growing in absolute terms due to a rapid population increase [1]. The need for traditional biomass energy, mainly fuelwood and charcoal, places a high burden on forest resources in many developing countries [2]. One of the major problems of current patterns of traditional woodfuel is a low energy efficiency of 7–12% and 11–19% for fuelwood and charcoal, respectively [3,4]. Especially in the world's drylands, deforestation leads to severe degradation of soils and energy poverty [5].

In Tanzania, traditional biomass accounts for 92% of the energy supply [6]. Access to electricity in Tanzania is one the lowest in the world. In 2001, only 10% of the population had access to electricity and only 2% in rural areas [7]. The low electric load density and the use of relatively expensive generation technology in isolated grids, leads to relatively high costs for electricity supply compared to national-grid-connected households [8]. Kerosene is the most widely used fuel for lighting [7] and increasing kerosene prices pose an additional burden on many rural households.

The semi-arid eastern part of Shinyanga region in Tanzania, was chosen as a case study area. It is considered representable for a dry region in Africa where energy poverty is prevalent. Fuelwood scarcity in rural Shinyanga has led to commercialization, because for many women the distance to natural woodlands is too long to walk. In 1998 it was surveyed that 62% of the population was buying fuelwood. As a result, fuelwood consumption is considerably lower as the Tanzanian average [9]. To combat uncontrolled deforestation, the government imposes permits for legal wood production from both public and private land, against an annual registration fee. Furthermore, taxes are levied on each unit of wood produced. However, because of a lack of law enforcement, the majority of charcoal and fuelwood is produced illegally [10]. Charcoal is sold in two qualities: locally produced, lower quality acacia charcoal and higher quality Miombo charcoal, produced in the sub-humid West Shinyanga and Tabora regions.

To decrease local energy poverty, combat forest and land degradation and as an intermediate step towards a modern energy provision, small-scale sustainable biomass energy production could be an effective tool. However, since yields are relatively low and people are generally poor, economic constraints towards implementation are serious. This study aims to explore the economic feasibility of implementing a sustainable biomass energy supply in semi-arid conditions on the smallholder level. Various alternative systems are possible. In Tanzania, agroforestry systems are well-recognized as a technology that can significantly improve the rural energy situation [11,12]. Furthermore, planting trees for CO_2 mitigation could provide income for local communities by trading 'carbon credits' and at the same time provide a sustainable source of fuelwood [13,14]. Alternatively, woodfuel could be replaced by an alternative energy carrier, like plant oil from the shrub Jatropha *curcas L.* On Jatropha oil production, limited literature on economic costs and benefits could be found [15–18]. Furthermore, comparative cost/benefit analysis of such systems could not be found. In order to determine the most feasible biomass energy system in semi-arid Shinyanga, this study analyzes and compares the economic costs and benefits for smallholders of these three different biomass energy supply systems: (1) A small-scale forestation project for carbon sequestration, which can be a sustainable source of fuelwood, (2) a short rotation woodlot for the sustainable production of fuelwood, charcoal or poles and (3) a Jatropha plantation, thereby using the oil as a substitute for fuelwood or for rural electrification.

1.2. Research background

The eastern part of Shinyanga region is a part of the vast semi-arid highland plateau in central Tanzania, which covers up 30% of the total land surface [19,20]. Rainfall is unimodal but variations in rainfall pattern and quantity are large. Historically, Shinyanga was covered by Miombo woodlands towards the west and acacia savannah towards the east. However, massive deforestation for the expansion of livestock and agriculture led to severe land degradation and water shortage [21]. From 1986 this trend was successfully slowed down and reversed by encouraging traditional land management based on regeneration [9,21]. Shinyanga is one of Tanzania's poorest regions with an average income of US$$_{2007}$ 186 and US$$_{2007}$ 400 for rural and urban households, respectively [7,19,22–25]. About 80% of the population belong to the Sukuma, who are agro-pastoralists. Shinyanga has by far the largest livestock population in Tanzania, resulting in severe overgrazing [26,27]. Over 46% of the land surface is considered to be arable land [25] and agriculture is the main economic activity. Maize and sorghum are the main staple crops, while cotton and tobacco are the main cash crops [19]. The yields in Shinyanga are below the Tanzanian average, which is mainly because of the inherent low soil fertility, low fertilizer inputs, poor rainfall and poor traditional crop management [9]. Crop production used to be characterized by shifting cultivation and long fallow periods. Due to increasing population pressure, this has changed to almost permanent cultivation [9]. Nevertheless, smallholders are generally more constrained by their labour capacity as by their land capacity, as the average farm size is still the largest in Tanzania [28].

1.3. Carbon forestry

Both the national and local governments have undertaken several initiatives towards forest planting in Shinyanga. These initiatives were largely unsuccessful mainly because of poor forest management due to a lack of public responsibility for maintaining the forest [29]. Potentially, this could be improved by trading carbon credits obtained from forestation, thereby rewarding good forest management. Afforestation and reforestation activities are included in the Clean Development Mechanism (CDM) under the Kyoto Protocol, using temporary, expirable carbon credits [30]. A key criterium for this mechanism is so-called *additionality*. Greenhouse gas reduction should be additional to the baseline, meaning that projects that are already economically feasible without the benefit of trading carbon credits are not eligible under the CDM.

Parallel to the CDM, a voluntary market for carbon offsets has emerged. Many voluntary afforestation projects follow general CDM guidelines [31]. In this analysis, both trading Certified Emission Reductions (CERs) under the CDM and Voluntary Emission Reductions (VERs) on the voluntary carbon market are analyzed. These carbon trade mechanisms are not included in the other two systems, rotational woodlots and Jatropha oil production. Rotational woodlots are already practised in Shinyanga and are likely to be economically feasible in the baseline, thus not

complying to the additionality criterium. Jatropha shrubs are simply not eligible as carbon sinks within the CDM mechanism.

In order to decrease the CDM transaction costs for smaller size projects, 'lighter' methodologies were developed, which may not generate more than 8 ktonne CO_2 equivalent per annum and are specifically aimed at low-income communities and smallholders [30], since the combined effort of groups of smallholders can store a significant amount of CO_2 on smallholder land [14,32]. However, this does not stimulate fuelwood production, since smallholders would not harvest any wood when the benefits of carbon income are higher as the opportunity costs of harvesting and selling fuelwood or timber, and vice versa. Alternatively, marginal general land can be used for a more centrally organized carbon forest. General land falls under local customary law and is used for grazing, as is basically all land in Shinyanga. In order for a carbon forestry project to be successful, therefore the local population has to be involved and benefit from the project, so that competition for land is avoided [33,34]. For example, forestation on such degraded grasslands can significantly improve fodder production, since different fodder resources like foliages, including leaves, pods and seeds become available [34–36]. Furthermore, apart from fuelwood, non-wood forest products such as herbal medicines, mushrooms, meat from small wildlife, gum, honey from beekeeping can be obtained from such woodland [19].

1.4. Rotational woodlots

Various agroforestry technologies exist in Shinyanga for the purpose of improving fuelwood supply, fodder production and combating soil degradation. For each purpose, different tree species are preferred by local smallholders [9]. When combining tree planting and crop production, management efforts benefit both trees and crops. In this way, both land and labour utilization can be optimized [37]. When agroforestry is focussed on wood production, short rotation woodlots are practised, using fast-growing tree species [38]. Rotational woodlot technology involves growing of trees and crops on farms in three inter-related phases. During the first phase, trees and crops are planted. After this establishment phase, the tree crown cover causes crop yields to become uneconomical. In this phase the area is left fallow and cattle is allowed to graze. At the start of the last phase, the trees are harvested and crops are planted in between the tree stumps. Coppice shoots are pruned so that single new stems emerge [39]. The trees not only have the capacity to provide wood and fodder, but can also function as a natural fertilizer by fixing nitrogen in the soil, which increases crop yields. Yields can thus be maximized by using smart combinations of trees and crops.

1.5. Jatropha oil production

In Sub-Saharan Africa, producing biofuel from the shrub *Jatropha Curcas L.* (hereafter named as Jatropha) is by many regarded as a promising alternative for rural communities [15–17,40,41]. Jatropha grows relatively well on poor soils and on severely degraded land. It is reported that Jatropha is suitable for reclaiming marginal land, though seed production under marginal conditions is not yet validated [42]. Potential seed yields strongly differ per location, management method and variety and range from 0.4–12 tonne per hectare after five years of growth [15]. Jatropa needs a minimum of 600 mm of rain annually to be productive, but is able to withstand long droughts, in which it sheds its leaves [15]. Jatropha is traditionally used for soap making, as a medicine and for protective hedges around fields, since its leaves and fruits are poisonous [15,16]. It is presently still a wild plant that is not cultivated through variety research [43]. Its seeds contain non-edible oil, which can be extracted by cold pressing, using a manual ram press or a mechanic oil expeller. The latter has a significantly higher oil extraction rate, but against much higher investment costs [16]. The remaining seedcake is an excellent organic fertilizer [15,44]. Because of its high viscosity, filtered Jatropha oil can generally not be used instantly as a fuel in conventional diesel engines, electricity generators, wick-lamps or wick-cooking stoves [18], though Jatropha oil can be blended with diesel [45]. For household applications like cooking and lighting, solutions towards the use of Jatropha oil are hardly available. One plant oil cooking stove could be found [46].

The three systems will be compared based on cost/benefit analysis using the present situation in East Shinyanga as baseline. The methodology for analyzing this baseline and the three biomass energy systems are explained in chapter 2. In chapter 3, the input data is presented after which the results are presented in chapter 4. Finally, this analysis is discussed and conclusions are drawn.

2. Research methodology

2.1. System definition

2.1.1. Carbon forestry

To restore the natural value of the area, a combination of indiginous tree species with fast-growing exotic species is planted. Seedlings are raised in nurseries during the dry season and spotplanted at the start of the wet season, during which vegetation is removed around the seedlings. It is assumed that the first three years, the forest is closed for livestock to avoid seedling destruction. To decrease competition for water and nutrients, vegetation is slashed during this period. In order to reduce the risk of fires, fire lines are constructed and maintained. A wide spacing of trees is needed to create vegetation for cattle. Tending operations such as thinning or pruning are avoided so as to allow accumulation of biomass [34]. It is further assumed that after seven years of initial growth, 10% of the annual biomass increment is reserved for wood production for the local community, in anology with a present project in Tanzania which is in the CDM-pipeline [47]. Fuelwood is produced from prunings and selective felling. Fuelwood obtained from the forest is deducted from the carbon stock, since the indirect benefit of avoided deforestation by providing a sustainable fuelwood supply is not eligible as a source of carbon credits under the CDM. A complete overview of the costs and benefits of this system are given below (Fig. 1).

2.1.2. Rotational woodlots

This cost/benefit analysis is largely based on an experiment in which *Acacia polyacantha* was grown for seven years on farm land in Shinyanga [9,39]. *A. polyacantha* is an indiginous, fast-growing, coppicing, termite resistant and nitrogen fixing species that performs well in semi-arid Shinyanga and is locally preferred for fuelwood and timber, despite of its sharp thorns. Fodder is produced by its pods, seeds and leaves [48]. In this analysis various configurations will be analyzed: a monoculture and intercropping of maize. Furthermore, the harvested wood can be used for poles, charcoal or fuelwood and production can be done legally or illegally. Trees are harvested after seven years of growth [39]. To create a constant annual wood supply, the woodlot area is divided in seven strata. It is assumed that the coppices will produce the same amount of wood as the first rotation. Slashing is practised for three years, after which cattle is allowed to graze. In case of intercropping, the land is ploughed for maize production and trees are planted in between. Twice per growing season, weeding is practised [34]. Maize cultivation is only economical during the first two years of tree establishment because of shading [39]. Because of the establishment costs and increasing maize yields over multiple rotations, the rotational woodlot was analyzed over a period of three rotations (Fig. 2).

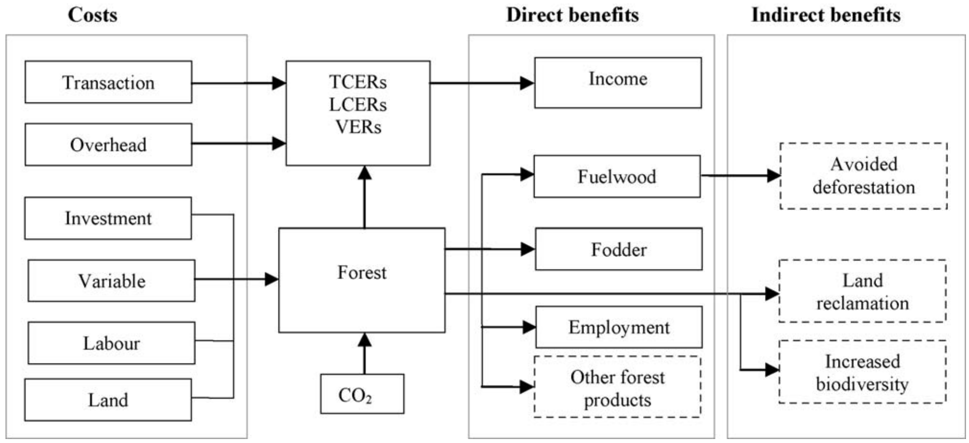

Fig. 1. The costs and direct and indirect benefits of carbon forestry in semi-arid Shinyanga. Benefits with a dotted line are not accounted for in the cost/benefit analysis.

2.1.3. Jatropha oil production

Both a Jatropha plantation with intercropping on arable land and a Jatropha monoculture plantation on degraded land are analyzed. In case of arable land, Jatropha is temporary intercropped during the first five years using understory crops like onions or groundnuts, after which the shading effect of the fast-growing Jatropha shrubs prevents further intercropping. To maximize the number of branches on each shrub, every four years the Jatropha shrubs are pruned [49]. Spotweeding is only needed during the first three years, after which the shading of the Jatropha shrub decreases vegetation growth and competition for water and nutrients is minimal. To allow fast growth, cattle manure is applied annually. When Jatropha oil is produced, the remaining seedcake is used as a fertilizer, instead of cattle manure. Irrigation is not practised. The farmer has multiple options: seeds can be directly sold to a biofuel producer or oil can be produced by a ram press, after which it can be sold, used for household cooking, for local electricity generation, using a generator, or alternatively, for soap production. For comparative reasons, the lifetime of the plantation is assumed to be equal to the lifetime of the rotational woodlot, which is 21 years (Fig. 3).

2.2. Indicators

2.2.1. Economic indicators

The economic feasibility of the three biomass energy supply systems is analyzed over the project lifetime, based on the Net Present Value (NPV) per hectare, the discounted return on labour and the discounted production cost of biomass energy, all relative to a baseline situation. The return on labour is the average discounted financial benefit per unit of labour input over the project lifetime. The discounted production cost of household biomass energy is best expressed both in cost per physical unit and in cost per energy unit, were energy is expressed both in primary energy and utilized heat.

2.2.2. Baseline assessment

In order to determine and compare the economic feasibility based on these indicators, the baseline situation of agriculture and grazing is translated into the opportunity cost of land, the shadow cost of labour and the shadow cost of energy. To collect data, a small survey was carried out around Shinyanga town (see Appendix A).

The opportunity cost of land is equal to the production on that land in the absence of the project [50]. It is assumed that agricultural land would be rented out for cultivation during the wet season and grazing during the dry season, if it would not be utilized by the owner. The monetary renting price is assumed to be the opportunity cost of land. However, agricultural land is not cultivated every year, to prevent soil depletion. Based on Ramadhani et al. [12], three years of fallow after two years of maize cultivation is assumed, meaning that land can be rented for agriculture only in two out of five years. In the case of marginal land, be it privately owned or claimed general land, the opportunity cost is assumed to be equal to the grazing rent price, since all land is used for grazing in Shinyanga.

The cost of labour is hard to define in rural Shinyanga, since land workers are often paid in natural payments, like food or land. The

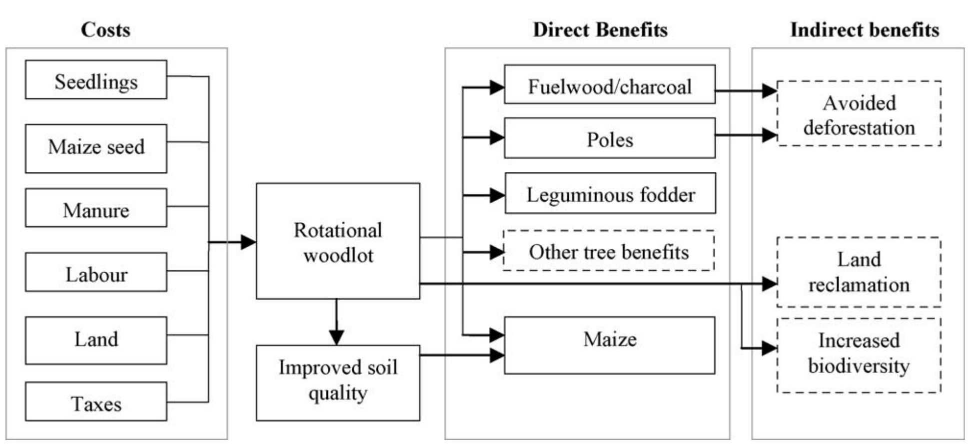

Fig. 2. Costs and direct and indirect benefits of the rotational woodlot system. Benefits with a dotted line are not accounted for in the cost/benefit analysis.

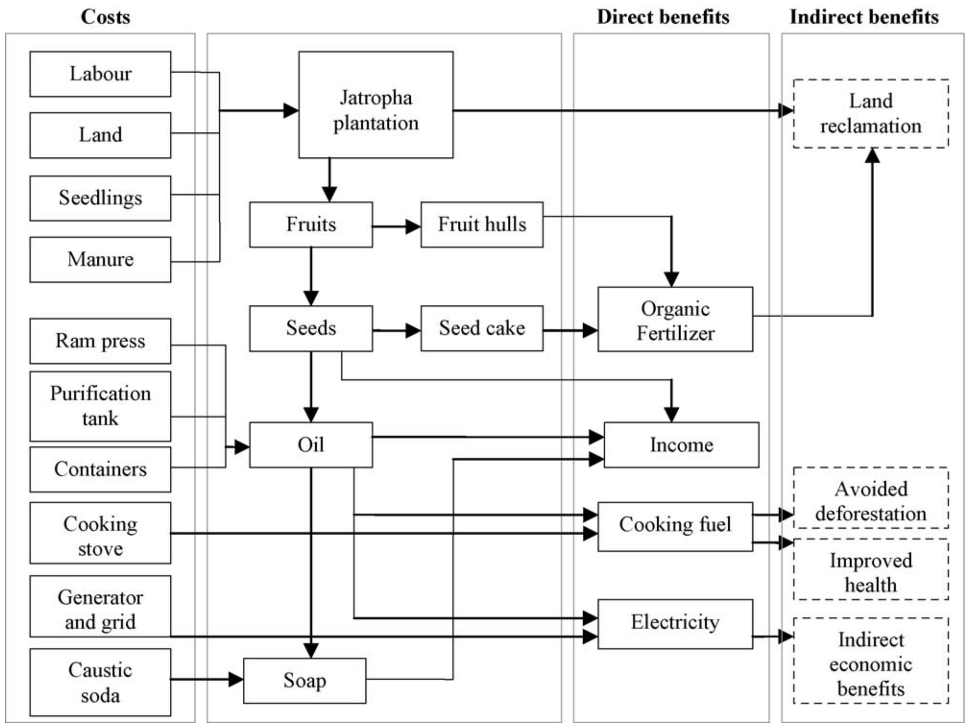

Fig. 3. The potential costs and direct and indirect benefits of the Jatropha plantation. Benefits with a dotted line are not accounted for in the cost/benefit analysis.

official Tanzanian minimum wage rate of US$$_{2007}$ 3.06 per man-day is not often applied and is therefore a too optimistic proxy [37]. The return on labour expresses the financial benefit per unit of labour and is obviously higher for a land owner as for a landless farmer who has to rent land. The shadow cost of labour is equal to the marginal rate of production of the worker in the absence of the project [50] and is assumed to be equal for the landless farmer and the landowner. This is based on the assumption that in the absence of the project a land owner can choose to cultivate his land or rent it out. In case the land owner would hire landworkers for cultivation, these landworkers would earn a wage which would still leave the land owner with a benefit equal to the opportunity cost of the land. Both, the shadow cost of labour and the return on labour were estimated by analyzing the economics of the most common agricultural activity in most parts of semi-arid Shinyanga: maize production (See Appendix C). The NPV of maize production is used as the baseline for comparison of the biomass energy systems and is defined as zero. This follows from the assumption that the labour, land and seed costs are exactly compensated by the benefit of trading maize.

$$W_{\text{sh,agro}} = \frac{(Y_{\text{maize}} \times P_{\text{maize}} - C_{\text{maize}} - C_{\text{land,agro}})}{L_{\text{total}}} \quad (1)$$

$$W_{\text{rl,agro}} = \frac{(Y_{\text{maize}} \times P_{\text{maize}} - C_{\text{maize}})}{L_{\text{total}}} \quad (2)$$

in which: $W_{\text{sh,agro}}$ = shadow cost of labour in the agricultural sector (US$/man-day) $W_{\text{rl,agro}}$ = return on labour in the agricultural sector (US$/man-day) Y_{maize} = average maize yield (tonne/ha/year) P_{maize} = market price of maize (US$/tonne) C_{man} = total management costs for maize cultivation (US$/ha/year) $C_{\text{land,agro}}$ = land rent price for agricultural land (US$/ha/year) L_{tot} = total annual labour needed (man-days/ha/year).

The baseline cost of energy was analyzed for fuelwood, charcoal, kerosene and off-grid electricity production. When fuelwood is collected for 'free' from natural forests, the shadow costs of fuelwood is best expressed as the opportunity cost of the time spend by women on collecting. Market prices are often bad indicators for the shadow cost of a good [50], since the use of the market price of fuelwood is constrained by the market access. Yet, because of limited information on the time needed to collect a headload of fuelwood, the locally surveyed market price was used. For charcoal, the farm-gate price of local Acacia charcoal, was used (see Appendix A).

For determining the baseline cost of electricity, the Tanzanian parastatal electricity company TANESCO is assumed to provide power generation and a small grid. A connection fee is charged to obtain access to a grid, after which electricity can be used against a fixed tariff. However, because rural electrification is subsidized, the price of electricity in the baseline does not reflect the real cost. The following formulas were applied.

$$\text{COE}_{\text{elec}} = P_{\text{ele,TAN}} + \frac{(\alpha \times 1 + C_{\text{service}})}{E_{\text{elec}}} \quad (3)$$

$$\alpha = \frac{d}{1 - (1 + d)^{-L}} \quad (4)$$

in which: COE_{elec} = total cost of electricity (US$/GJ) P_{TAN} = fixed TANESCO electricity tariff (US$/GJ) α = capital recovery factor I = initial investment (connection fee) (US$/HH) C_{service} = annual service costs (US$/HH/year) E_{elec} = annual electricity consumption (GJ/HH/year) r = real discount rate (corrected for inflation) L = payback time of the investment (years).

The stove efficiency must be taken into account to obtain the real cost of energy in terms of utilized heat. In the baseline analysis, both conventional and improved fuelwood and charcoal stoves were included. It is assumed that for an electricity stove, a plant oil stove and a burnt brick woodfuel stove a loan is needed. The capital recovery factor was determined as in formula (4). For other stoves, the annual costs are determined by dividing the initial cost over the stove lifetime.

2.2.3. Carbon forestry

As a guideline, an appropriate small-scale forestation methodology of the UNFCCC was applied [51]. Monitoring, verification

and issuance of carbon credits is carried out after each commitment period of 5 years. The mitigated CO_2 after each commitment period is determined as follows.

$$M_{cp} = \sum_{t=n}^{t=n+5} B_t \times (1+r) \times A \times 0.5 \times \frac{44}{12} \tag{5}$$

in which: M_{cp} = CO_2 mitigated in commitment period (tonne) B_t = annual above-ground biomass increment (tonne dry matter/ha/year) r = root-to-shoot-ratio (dimensionless) A = forest area (ha) 0.5 = carbon fraction of dry matter (tonne C/tonne dry matter) 44/12 = conversion factor from tonne C to tonne CO_2 (tonne C/tonne CO_2)

In the CDM mechanism, the project developer can choose between so-called short-term CERs (tCERs), that expire each 5 years, and long-term CERs (lCERs), that expire after the project crediting period of 30 years. The value of a temporary CER in relation to a permanent CER is determined as follows [52].

$$P_{\text{expiringCER}(0)} = P_{\text{CER}(0)} = \frac{P_{\text{CER}(t)}}{(1+d)^{\text{ET}}} \tag{6}$$

in which: $P_{\text{expiringCER}(0)}$ = price of an expiring CER in year 0; $P_{\text{CER}(0)}$ = price of a permanent CER in year 0; $P_{\text{CER}(t)}$ = price of a permanent CER in year t; d = real discount rate (of the credit buyer); ET = expiring time of temporary credits.

A constant CER market price over the crediting period of the project is assumed. Furthermore, it is assumed that CERs are only sold to a credit buyer every 5 years after each verification. A voluntary market standard that has more or less the same quality level as the CDM standard was assumed. SGS Forestry, a so-called Designated Operational Entity under the CDM, developed the Qualifor program for afforestation projects on the voluntary market. Since expiring credits cannot be issued on a voluntary basis, the issue of permanence of carbon sequestration is approached by reserving part of the carbon stock as a buffer, which size depends on a risk assessment. In case of fires, pests, illegal logging, etc., this buffer is used [53]. In this analysis, the Qualifor permanence-guideline was used for VER issuance.

$$\text{VER}_{cp} = M_{cp} \times (1-B) \tag{7}$$

in which: VER_{cp} = VERs available in commitment period; M_{cp} = CO_2 mitigated in the commitment period (tonne); B = buffer size of forest (%).

Transaction costs are involved in both the CDM and the voluntary project cycle. Monitoring of carbon stocks can be carried out by a local community [54]. The forest size is constrained by the maximum annual CO_2 mitigation of 8 ktonne per year for small-scale projects under the CDM. Forestation costs consist of investment costs independent of the forest size, variable investment dependent on the forest size and annual costs. The cost of land consists of an annual land rent fee, which the project developer has to pay to the Tanzanian government for a title deed [55]. For this analysis, we assumed no net improvement in fodder production, which is a conservative estimate since pastoralists are likely to benefit from leguminous fodder sources that become available. The shadow cost of the produced energy is assumed to be equal to the opportunity cost of receiving carbon payment for the harvested wood, plus the cost of harvesting the wood by ox-cart.

2.2.4. Rotational woodlots

The total annual benefits consist of harvested wood, tree and herbaceous fodder and maize production from intercropping. For charcoal production, the wood yield is multiplied by the kiln efficiency on a weight basis. From the leguminous fodder products, only the benefit of leguminous fodder which is yielded when harvesting the tree stems is included in this analysis. Tree pods and fruits falling down during the growing period of the trees are not included, because of a lack of information on the quantity and value of this fodder source. As a conservative estimate, the value per tonne of leguminous fodder is assumed to be equal to herbaceous fodder.

$$B_{\text{leg}} = \left(\frac{C_{\text{grazing}}}{V}\right) \times Y_{\text{wood}} \times (\text{BEF} - 1) \tag{8}$$

in which: B_{leg} = benefit of leguminous fodder production (US\$/ha) C_{grazing} = land rent cost of grazing land (US\$/ha/year) V = baseline annual vegetation growth (tonne dm/ha/year) Y_{wood} = wood yield (tonne DM/ha) BEF = Biomass Expansion Factor (tonne DM total biomass/tonne DM wood).

The cost of rotational woodlots can be divided in investment costs (seedlings, manure and maize seed), annual labour costs, the opportunity cost of land and additional government fees. It is assumed that labour for wood chopping is only needed for the percentage of the yielded wood that is used for fuelwood or charcoal production. When intercropping is practised, spotweeding and slashing are replaced by overall field weeding, which is allocated to maize production, since this activity would take place anyway. As such, the additional benefit of intercropping compared to a monoculture woodlot can be determined.

2.2.5. Jatropha oil production

For this analysis, it is assumed that the local market value of Jatropha oil would be equal to the value of diesel minus taxes and minus the cost of transesterification to biodiesel. When Jatropha oil is used for cooking, the benefits are expressed in the avoided expenses of fuelwood on the basis of utilized heat:

$$B_{\text{J,cooking}} = \sum_{t=1}^{t=21} Y_{\text{oil},t} \times D_{\text{J}} \times E_{\text{J}} \times \eta_{\text{stove,J}} \times \left(\frac{\text{COE}_{\text{fw}}}{\eta_{\text{stove,fw}}}\right) \tag{9}$$

in which: $B_{\text{J,cooking}}$ = total benefit of cooking on Jatropha oil (US\$) $Y_{\text{oil,t}}$ = Jatropha oil production in year t (l) D_{J} = density of Jatropha oil (kg/l) E_{J} = energy content of Jatropha oil (MJ/kg) $\eta_{\text{stove,J}}$ = efficiency of a Jatropha oil cooking stove COE_{fw} = cost of energy of fuelwood (US\$/GJ) $\eta_{\text{stove,fw}}$ = average fuelwood stove efficiency.

It is assumed that Jatropha seedlings are not available and have to be raised during the dry season. Therefore, a loan is needed, which is paid back over a period of 10 years, using a capital recovery factor (formula (4)). Further costs for Jatropha seed production are the cost of manure the opportunity cost of land and labour costs for planting, manuring, pruning, weeding, slashing and seed harvesting. In case of Jatropha oil production, additional investment is needed for a manual ram press and storage vessels. Additional labour is needed for oil pressing and filtration.

For calculating the cost of electricity, it is assumed that all the annually produced oil is used for electricity production by using a generator and a small grid. Furthermore, it is assumed that the electrification project is started when the annual Jatropha production is maximized after 8–10 years of growth [49]. The cost of electricity is determined as follows.

$$\text{COE}_{\text{elec,J}} = \frac{(\alpha \times ((P_{\text{peak,hh}} \times C_{\text{gen}} + C_{\text{grid,hh}}) \times N_{\text{hh}} + C_{\text{adap}}) + OM + Y_{\text{oil}} \times COE_{\text{J}})}{(Y_{\text{oil}} \times \eta_{\text{gen}})} \tag{10}$$

in which: $\text{COE}_{\text{elec,J}}$ = cost of electricity using Jatropha oil as a fuel (US\$/GJ)/(US\$/kWh) $P_{\text{peak,hh}}$ = household peak demand (W/hh) C_{gen} = specific generator cost (US\$/W) $C_{\text{grid,hh}}$ = cost of a power line, socket and light point (US\$/hh) N_{hh} = number of households that are connected C_{adap} cost of adapting the generator to run on Jatropha oil (US\$) OM = annual operation and maintenance cost of the generator (US\$/year) Y_{oil} = annual oil production (GJ/year) COE_{J} = cost of energy of Jatropha oil (US\$/GJ) η_{gen} = generator efficiency.

Using Jatropha oil for soap production is rather straightforward. One kg of soap is produced by boiling oil, water and caustic soda. Besides the cost of caustic soda, there are costs for labour, packaging and fuelwood for boiling. The soap can be sold to a trader for a farm-gate price.

3. Input data

The input data for the estimation of the opportunity cost of land and the return on labour based on maize cultivation can be found in Appendix C. Input data for the cost/benefit analysis is presented in Appendix D. To collect data, a small survey was carried out in villages around Shinyanga town (see Appendix A), even as interviews with local experts and civil servants. Additional data was obtained from both local and published literature.

The total accumulated uncertainty for the main input parameters is included in this analysis (see Appendix D). The following uncertainty ranges were used: the baseline shadow cost of labour of maize cultivation is determined to be US$1.43/man-day and the baseline return on labour is US$1.88/man-day (see Appendix C). The uncertainty in the shadow cost of labour is assumed to vary from the international poverty line of US$1.00/man-day, to the official Tanzanian minimum wage rate of US$ 3.06/man-day. Discount rates have a major impact on cost/benefit analyses and can be prone to significant fluctuations. In recent years in Tanzania, the discount rate has fluctuated from 13% in March 2005 to 21.4% in April 2007. Furthermore, inflation has fluctuated from 3.5% in 2003 to 6.5% in 2006 [56]. Combined, the real discount rate may fluctuate between 6.8% and 17.9%. The base case woodlot MAI is relatively high since *A. polyacantha* is a relatively fast-growing species. Therefore, the uncertainty ranges more towards lower MAI values. Best practise charcoal kiln efficiency was used in this analysis, though the kiln efficiency can decrease to 10% in case of bad kiln management [72]. The price of charcoal can increase rapidly in times of scarcity at the end of the wet season (see Appendix A). The Jatropha plantation size is assumed to vary from 1 acre to 3 hectare, which is the maximum capacity of a ram press in the base case. Reasonable uncertainty ranges for other important parameters were estimated.

4. Results

In this section, the results are presented and compared per indicator, namely the NPV, the return on labour and the cost of energy.

4.1. The Net Present Value

The NPV per hectare of each system is depicted in (Fig. 4).

Carbon forestry in East Shinyanga would result in a negative NPV. The main reasons are the relatively low MAI and the need for extensive fire risk management. This causes the per hectare management costs to outweigh the per hectare benefits. To mitigate 8 ktonne of CO_2 annually, 1558 ha of forest land is needed. Trading lCERs is the most attractive option with an NPV of US$-261/ha, because at the first CER issuance after 5 years, relatively high-value lCERs can be traded, since these will be valid for 25 years. The benefits of VERs are significantly reduced by the buffer size. When lCERs are traded, the total NPV of this project is US$-407,311. The NPV is rather sensitive to the MAI, but only at a mean increment of 5.2 tonne DM/ha/year a breakeven between costs and benefits would be attained. At such an increment the forest size is reduced to 597 ha. However, a MAI of 5.2 tonne DM/ha/year is not realistic in dry forests, which make up 90% of all the forests in Tanzania [73,74]. At a MAI of 2 tonne DM/ha/year, the NPV breaks even at a CER market price of €27.24, when mitigating 8 ktonne CO_2 per year. Thus a 65% price increase is needed compared to the present market price. Transaction costs account for only 9%, while labour covers 41% of the total costs. The large land area needed leads to relatively high land labour costs (25%) and specific investment costs (15%), which are mainly the costs of tractors needed for slashing and fireline maintenance. Land labour is foremost needed in the first years of the project establishment. Planting provides 93 fte of labour in year 0. Slashing and fireline maintenance provides 56 fte in year 1–3, but only 3 fte from year 4 and onwards. Fuelwood harvest accounts for only 2% of the total cost NPV.

The NPV of rotational woodlots is highly positive, up to US$1,165/ha when producing poles, charcoal and maize. Intercropping of maize adds significantly to the NPV per hectare, mainly because of the maize yield increase after the first rotation as a result of the improved soil condition. This causes the average annual maize yield per hectare in the rotational woodlot to be even slightly higher as the maize yield in the baseline. However, during the first rotation, maize yields are lower as in the baseline and there are additional costs for plantation establishment. The benefits of both leguminous and vegetation fodder are insignificant compared to the benefits of wood and maize. Labour is the largest cost factor, accounting for 51% of the NPV of the project costs, followed by land (33%) and seedlings/manure (16%). Trading poles is attractive since less labour is needed for wood chopping and thus higher profits can be made. When taxes are included, it is

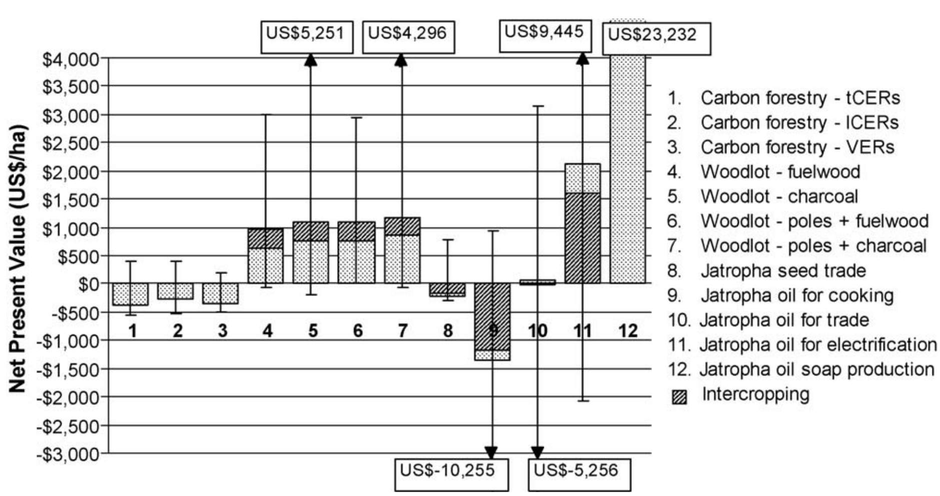

Fig. 4. NPV per hectare for carbon forestry, rotational woodlots and Jatropha systems in East Shinyanga. The striped bars indicate intercropped plantations. The error bars represent the accumulated uncertainty in the main input data, as presented in Table 15.

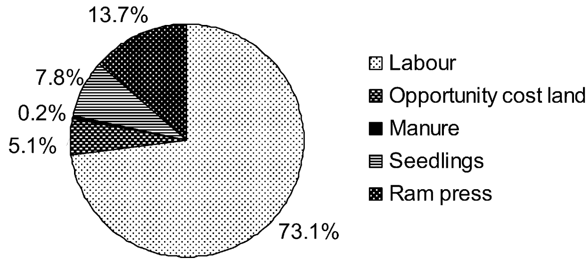

Fig. 5. Breakdown of Jatropha oil production cost factors for a 1 ha plantation, when intercropping.

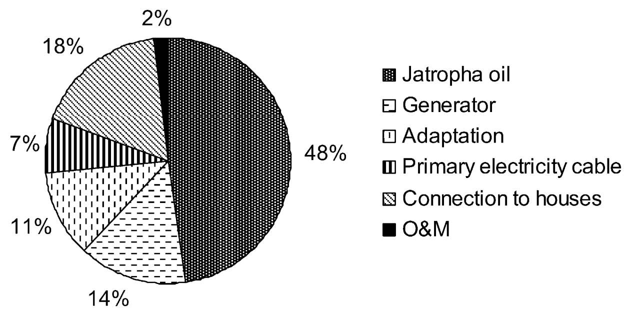

Fig. 6. Breakdown of annual electricity production cost factors when using Jatropha oil from a 1 ha monoculture plantation.

hardly economically feasible to establish a woodlot for commercial purposes. In a one hectare woodlot, the NPV is diminished to almost zero, mainly because of the high cost of the annual government license that is needed for legal production and trade. Taxes account for 63% of the cost NPV. Only at a woodlot size of 3.4 ha and 16 ha, the tax burden is decreased to the Tanzanian VAT of 20%, for fuelwood production and charcoal production, respectively. Though, a woodlot size of 3.4 ha is rather large for smallholders. Profits may also disappear when the wood yield and the market price of fuelwood are relatively low, at a relatively high labour cost and discount rate.

The economic feasibility of Jatropha oil strongly depends on its utilization. Of all the analyzed options, Jatropha oil production as a substitute for diesel in an off-grid electrification project is the most profitable energy related option per hectare. The production cost of Jatropha oil is about 50% lower as the observed diesel market price of US$$_{2007}$ 1.49/l in rural Shinyanga. On the other hand, the production cost of Jatropha oil is significantly higher as fuelwood production in the baseline, leading to a negative NPV for cooking on Jatropha oil. By producing soap, significant value can be added when investing limited labour and cash. However, this is presently a niche market. The local market for Jatropha soap is probably insignificant, though in urban areas there might be a larger market. Still, it can be expected, that a growing market would lead to a drop in the farm-gate price of Jatropha soap because of competition effects. The error ranges for all Jatropha oil options are large, which is mainly caused by uncertainty in the shadow cost of labour, since smallholder Jatropha oil production is relatively labour intensive compared to rotational woodlots. When land workers are paid the minimum wage rate, all energy options become strongly uneconomical.

Figs. 5 and 6 show cost breakdowns of Jatropha oil production and electricity production using Jatropha oil. On a 1 ha plantation basis, labour accounts for 71% of the cost NPV of Jatropha oil production. Seed harvesting, dehulling and oil pressing account for 91% of the labour needed. The share of the ram press in the production cost is relatively small and is declining with increasing plantation size. The opportunity cost of land is about equal for a monoculture or intercropping, because the yield benefit of intercropping on arable land is compensated by the lower opportunity cost of degraded land. This causes the production cost of Jatropha seeds to be basically equal for a monoculture and intercropping. However, the NPV per hectare diverges, because the spacing is denser on a monoculture plantation and thus more seeds can be produced per hectare. For Jatropha oil-based electricity production, considerable investments are needed, so that the fuel cost accounts for less than 50% of the total annual electricity production cost.

4.2. The return on labour

The return on labour for each system is depicted in Fig. 7: error margins for the return on labour are less wide as for the NPV, since uncertainty in the shadow cost of labour does not have an impact on the return on labour. In the case of carbon forestry, the return on labour for the local community is the official minimum wage earned for land work plus the benefit of fuelwood collecting (US$3.80/man-day), which is well above the reference return on labour of maize production.

For rotational woodlots, the return on labour is maximized for poles and fuelwood production on a monoculture (US$6.96/man-day), since this combination has the lowest labour demand per

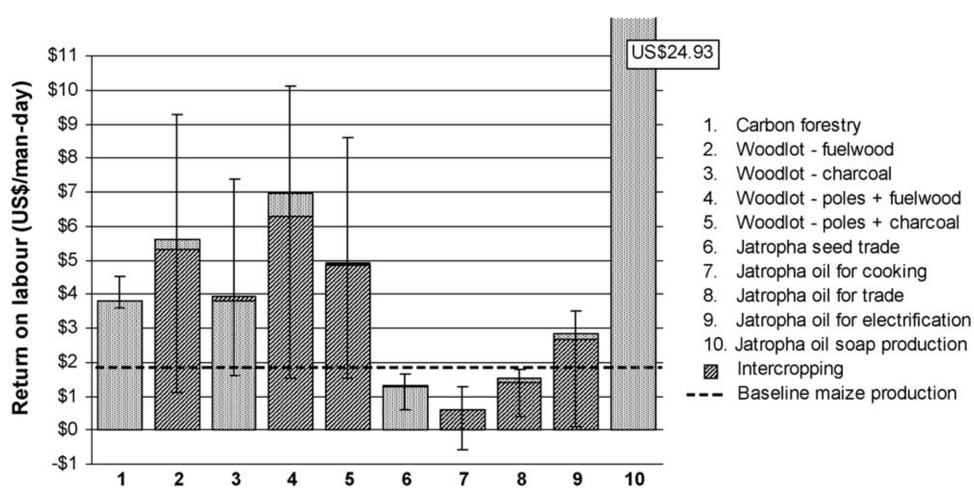

Fig. 7. Return on labour for carbon forestry, rotational woodlot and Jatropha systems in East Shinyanga. The striped bars indicate intercropped plantations. The dotted line indicates the baseline return on labour of maize cultivation (US$1.88/man-day). The error bars represent the accumulated uncertainty in the main input data, as presented in Table 15.

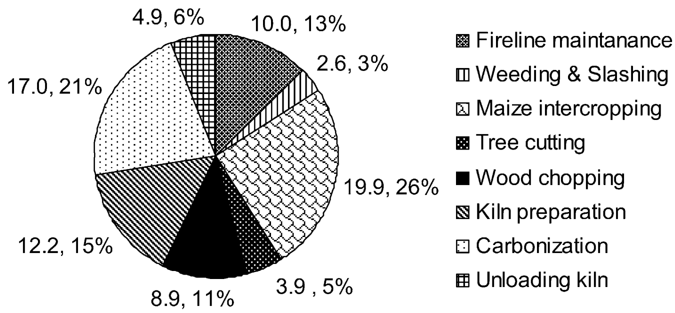

Fig. 8. Breakdown of annual labour needed for poles and charcoal production after year 7, when a constant wood supply is realized (in man-days/ha). .

hectare: 31 man-days, compared to 70 man-days for baseline maize cultivation (see Appendix C). Thus, a farmer who is constrained by land and wishes to maximize added value per hectare is better off when producing poles and charcoal from an intercropped woodlot, while a farmer with excess of land, but a labour constraint is better of when producing poles and fuelwood from a monoculture woodlot. Fig. 8 depicts a breakdown of the annual labour needed in the rotational woodlot when producing poles and charcoal after year 7, when a constant annual wood supply is realized: charcoal production is relatively labour intensive and accounts for 58% of the annual labour needed. 79 man-days/ha/year are needed for poles and charcoal production. Thus, with adding 9 man-days/ha/year, compared to maize cultivation, an additional NPV of US$1,165/ha and an additional return on labour of US$5.08/man-day can be realized. Furthermore, tree harvesting and charcoal production can be practised during the agricultural off-season so that labour competition with food production is avoided. The annual labour needed for sole fuelwood production, charcoal production or poles and fuelwood production is 50, 107 and 45 man-days/ha/year, respectively, when intercropping. The labour intensity of fuelwood production is 0.26 and 0.22 man-days/GJ for a monoculture and for intercropping, respectively. Converted to local units, this is about 29 min of labour per headload, indicating the time that can be saved on fuelwood collecting when producing fuelwood from a woodlot, since in East Shinyanga, fuelwood collecting can take up to several hours per headload. Charcoal production is significantly more labour intensive: 2.05 man-days/GJ for a monoculture and 1.91 man-days/GJ when intercropping (Fig. 8).

As for the Jatropha oil options, only electrification and soap production result in a return on labour which is above the baseline. In total 299 man-days are needed per year and per hectare to run the monoculture plantation under maximal production, which is more than 4 times the labour demand of maize cultivation. On average, 10.05 man-days/GJ are needed for production of Jatropha oil, which is about 3 h/l.

4.3. The cost of energy

Fig. 9 shows the cost of energy of the various energy carriers, both for the baseline as for the bio-energy systems, both in primary energy and utilized heat for cooking: remarkably, the most utilized baseline cooking technique, fuelwood on a 3-stone stove, is relatively expensive when expressed in cost of utilized heat (US$27.89/$GJ_H$). Using charcoal on a ceramic stove is about equally expensive as using fuelwood on a mud stove. Investing in improved stoves significantly lowers the cost of cooking. Most economical is using fuelwood on a burnt brick stove (US$7.27/$GJ_H$). There is a large gap between wood-based and fossil-based energy sources. Cooking on kerosine, a common practise in urban areas, is about three times as expensive as cooking on a 3-stone stove.

The value of fuelwood in the carbon forest can be defined by its opportunity cost: the benefit foregone when reserving 10% of the annual biomass increment for fuelwood production instead of trading carbon credits, which is US$1.18/GJ of wood. The cost of

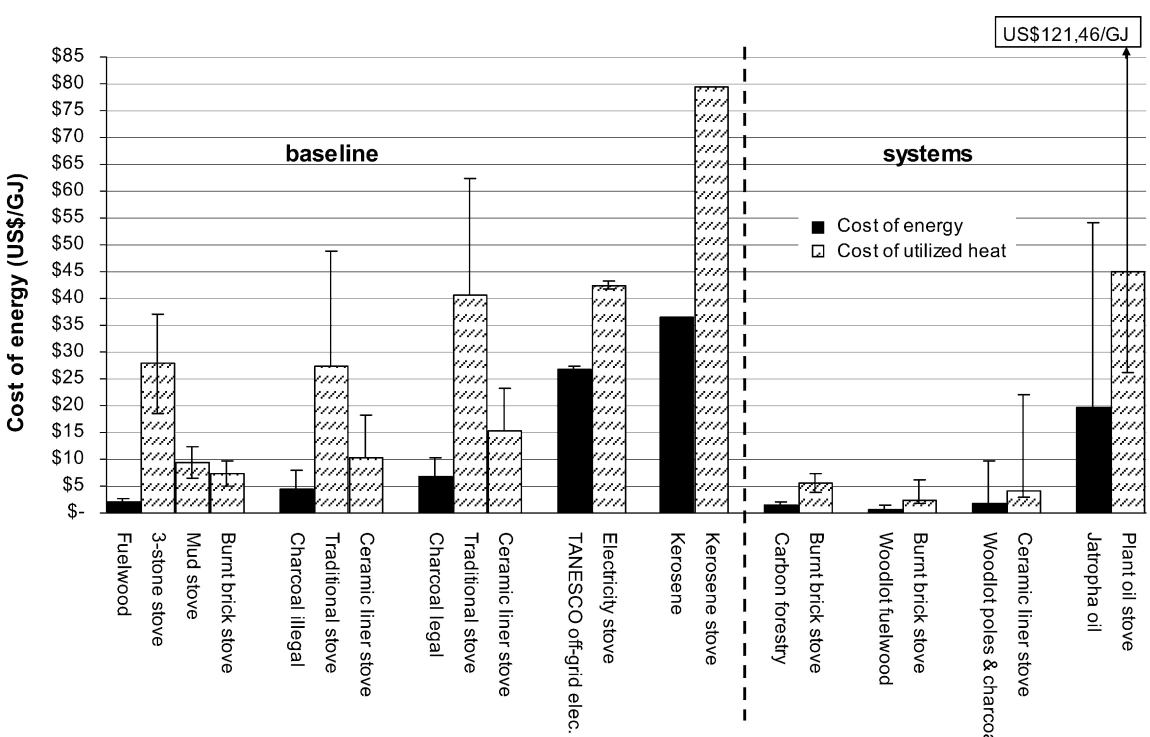

Fig. 9. Cost of energy for household cooking in rural East Shinyanga, both in terms of primary energy (black columns) and utilized heat (striped columns), using various cooking stoves. In case of the biomass energy systems, only the most efficient cooking stoves are shown. The error bars represent the accumulated uncertainty in the main input data, as presented in Table 15.

energy for the local community consists of the shadow cost of labour of harvesting the fuelwood, which is estimated to be US$0.28/GJ, when collected by ox-cart. The total cost is thus US$1.46/GJ. The value is lower as the market price of fuelwood, indicating that a carbon forestation project on smallholder land would not be realistic with present carbon credit prices. It is unlikely that there would be an incentive to preserve the forest, since the value of wood in terms of energy is much higher as the value of wood in terms of a carbon sink. In case of 10% fuelwood harvesting, after 7 years of growth, 312 tonne of wood can be harvested from the forest each year. This is enough to cover the demand of about 39 households, based on a per capita fuelwood demand of 1.20 tonne/capita/year (see Appendix B). When assuming a fuelwood market price of Tsh 600 per headload, the total NPV of the fuelwood benefit over the lifetime of the project is US$ 27,868, or US$17.88/ha.

Woodfuel produced from the rotational woodlot is the most economical option. It is considerably cheaper as the market price of fuelwood: US$0.53/GJ, compared to US$1.95/GJ in the baseline. The production cost price of charcoal when intercropping is US$1.71/GJ, which is also below the market price of fuelwood and only 38% of the market price of charcoal. When taxes are ignored, the cost of energy and the return on labour are independent of the woodlot size, since there are no fixed investment costs. However, taxes more than double the production cost of woodfuel for a 1 ha woodlot. Likewise, with a low kiln efficiency of 10% and when applying the minimum wage rate, the cost of charcoal can increase up to US$9.80/GJ. Per hectare, 161.5 GJ of fuelwood can be produced, compared to 97.2 GJ of charcoal, when applying a kiln efficiency of 30%. When correcting for best practise stove efficiency, the heat production is about equal for fuelwood and charcoal. A one hectare woodlot could provide enough fuelwood to fulfil the annual fuelwood demand of 1.3 households in Shinyanga, when using the current average cooking efficiency of 8%.

The production cost of Jatropha seeds is 118 Tsh per kg, which is above the market price of Tsh 100 per kg. Only at a seed yield of 3.2 kg/shrub/year, or a shadow cost of labour of US$1.35/man-day, the seed production cost will break even with the market price for Jatropha seed. Jatropha oil is relatively expensive. The production cost in a monoculture plantation is US$0.73/l, or US$19.60/GJ. This is slightly below the assumed local market price of US$0.75/l, however the benefit per man-day of work is lower as the baseline, caused by the fact that Jatropha oil production is rather labour intensive. Cooking on Jatropha oil is not economical compared to cooking on fuelwood, because of the relatively high cost of US$45/GJ utilized heat. Only at a market price, or a shadow cost, of Tsh 1129 per headload, or US$3.68/GJ, the benefit of avoided fuelwood consumption is large enough for Jatropha oil to become economically feasible. The sensitivity of the oil production cost as a function of seed yield is declining with increasing yields, since 66% of the production costs are variable labour costs for harvesting and pressing, which are assumed to be independent of the seed yield. A maximum seed yield of 1.5 instead of 2 kg/shrub/year would result in an oil production cost increase of only 11%.

The production cost of off-grid electricity using Jatropha oil was not included in the overview of household cooking in Fig. 9, because this is regarded as a much higher quality energy carrier which is not likely to be used for powering an electric cooking stove. The cost of the produced electricity is US$0.60/kWh, compared to US$0.79/kWh, when using diesel. Still, US$0.60/kWh is about 6 times more expensive as the subsidized cost of electricity in case of a TANESCO rural electrification project and is not likely to be affordable for many people. In case the estimated shadow cost of labour is increased to the value of the official Tanzanian minimum wage rate of US$3.06/man-day, the oil production cost will increase with 90%, to US$1.39/l.

5. Discussion

In this study, most input data is assumed to be constant over the project lifetime. In reality, the economy and the population of Tanzania are growing rapidly and it can thus be expected that these parameters will not be constant over a time span of 20–30 years. However, remote rural areas have been less affected by economic development, which is caused by a lack market access. Rapid economic development is mainly taking place around large urban areas like Dar Es Salaam at the Indian Ocean coast. Another problem that arises with cost/benefit analysis in a largely reciprocal society as rural Shinyanga, is the fact that many costs and benefits are hard, so not impossible to convert to monetary values. Apart from large uncertainties, this can cause significant distorsions in the analysis. Forest benefits from carbon forestry like pods and honey, for example, were not included in this analysis while it is likely that these benefits can be significant. Furthermore, the benefits of leguminous fodder in the rotational woodlot are small, but only the fodder yield when harvesting the trees is accounted for and the value per tonne of leguminous fodder is assumed to be equal to vegetation fodder. In practise, valuable sources of leguminous fodder are tree pods and falling leaves, which can be browsed by livestock during the years of tree fallow. This leguminous fodder is likely to have a higher value as vegetation fodder since it has higher nutritional value than vegetation fodder and is an important protein-rich supplement to the daily diet [36]. However, since data on the quantity of this browse fodder could not be found and a reasonable estimate could not be made, it was not included in the analysis.

The shadow cost of labour is another main uncertainty in cost/benefit analysis of smallholder agricultural systems, caused by the absence of a standard wage for agricultural labour. A constant average shadow cost was assumed in this research. In practise, a high labour demand during the agricultural harvesting season can lead to an increased biomass energy production cost. Furthermore, the shadow cost of labour is likely to depend on gender. Because of these monetary valuations of non-monetary goods, it is important not to decouple the outcomes of this study from their context. This poses the question whether it is possible to extend the outcome of this study to other semi-arid regions in Africa. Data collection in other semi-arid regions would in this case be a logical next research step.

From an institutional perspective, carbon forestry can be an attractive strategy to combat land degradation and improve local livelihoods. A carbon woodland in semi-arid Shinyanga has the potential to fulfil an important socio-economic function for a local community, by providing various forest products, like leguminous fodder, gum and resins, honey from bee-keeping, meat, mushrooms, ropes, herbal medicines, etc. In addition, there are indirect benefits like reduced deforestation, enhanced biodiversity and reclamation of degraded land. The latter benefit is especially valuable concerning the state of land degradation in semi-arid Shinyanga. Relevant data on the economic value of all forest products per hectare of planted woodland was not available. When including all these non-monetary benefits in an evaluation, donor organizations might be willing to help financing the gap between the costs and benefits of carbon forestry as determined in this analysis. Based on the presented input data, at a woodland size of 1,558 ha, about 50% of the forestation costs can be financed by the trade in lCERs, leaving a gap of about US$400,000, or US$261/ha.

In this study, a small-scale CDM project methodology, mitigating a maximum of 8 ktonne CO_2 per year, was assumed. However, this cap of 8 ktonne is disputable. In this study, the sensitivity analysis shows that small-scale forestation under the CDM is only economically feasible at a MAI of 5.2 tonne/ha/year, which is well above the MAI in Tanzania's dry forests. When the CO_2 cap would be set to 10 ktonne per year, the NPV breakeven point is reached at a MAI of 4 tonne/ha/year. The cap of 8 ktonne is

likely to significantly reduce the applicability of the small-scale forestation methodology under the CDM. It only allows projects in areas with a relatively high MAI, while most energy poverty is experienced in dry areas with a lower MAI.

Another inconsistency in the CDM forestation mechanism is the fact that some carbon sinks are excluded from the mechanism, while others are included. Jatropha shrubs can grow up to five meters, have a long lifetime and can regenerate marginal soils, but are presently not eligible as carbon sinks under the CDM mechanism. More research is needed on the consequences and risks of adding Jatropha shrubs as carbon sinks in the CDM. Also, reduced deforestation, created by providing an alternative for traditional woodfuel harvesting is excluded. Though, in the latter case, the complexity of verifying additionality of greenhouse gas reduction is large. The tool of carbon forestry as a measure to reduce greenhouse gas emissions demands a conservative approach in order to avoid fake CO_2 reduction and undermining of the mechanism.

Low labour productivity is a common problem for livestock keeping, agriculture and energy production in rural Shinyanga and other dryer parts of Tanzania. For sustainable development it is important that productivity is increased per unit of labour invested and per unit of land used, which is exactly the focus of agroforestry. By combining crop cultivation and tree growing, grazing, food production and energy demand are addressed, which results in a higher return on labour. In contrast, the government taxes on sustainable woodfuel production from private land are extremely high and do not coincide with the government policy to combat energy poverty and deforestation. While, one of the main advantages of woodlots is the fact that establishment on a very small scale is possible. Particularly in case of charcoal production, where the market is dominated by illegal charcoal, removal of the tax barrier on charcoal produced from private woodlots can lead to an increased competitiveness of legal charcoal. Although, it is unclear to what extend these government fees are issued in practise in rural areas, because of a lack of law enforcement, it is advised that taxes on sustainable woodfuel production from private land are removed.

The fact that Jatropha can grow on marginal land is often claimed as a large benefit, for the reason that this avoids competition with food production. However, a Jatropha plantation on general land in Shinyanga competes with livestock grazing, which will increase the grazing pressure elsewhere. Furthermore, competition with labour capacity for food production might be a larger constraint, since Jatropha oil production is very labour intensive. To scale up the market for Jatropha oil, more cost-efficient oil production is needed by means of a mechanic oil expeller. Such an expeller has a labour intensity of 3.6 man-days/tonne of seed [77], compared to 48 man-days/tonne seed when using a manual ram press [16]. This results in an annual saving in labour cost of US$6.73/GJ. In Tanzania, a mechanic oil expeller costs around US$2,000, excluding fuel and maintenance costs [81]. This is unlikely to be affordable for smallholders. Therefore, cooperatives could be promoted, in which farmers could participate. The production cost of electricity is determined to be US$0.60/kWh, which seems relatively expensive compared to the rate of about US$0.10/kWh for a subsidized TANESCO rural electrification project. However, Ilskog et al. reported an electricity price of US$$_{2007}$0.54/kWh for a private off-grid electrification project to be still economical [8]. From a government perspective, it might be desirable to produce biofuel for the national transport sector. However, for this purpose the produced Jatropha oil needs to be further processed, which demands more centralization of oil production, in which case farmers will only supply seeds. Furthermore, it is questionable whether smallholders should be encouraged to invest their labour capacity in Jatropha seed production, instead of food production when taking into account that the profit margin of Jatropha seed production is small, if not subsidized by the government.

6. Conclusion

Based on an estimated mean annual biomass increment of 2 tonne DM/ha/year, local fuelwood supply by means of a carbon forestry project in East Shinyanga is not economically feasible. The forest management costs per hectare are higher as the per hectare income from carbon credits, yielding an NPV of US$-261/ha when mitigating 8 ktonne of CO_2 on 1,158 ha of woodland. However, except for fuelwood benefits, forest environmental services for the local community are not included and can be significant.

Smallholder Jatropha oil production as an alternative fuel for household cooking is not economically attractive, since the cost of Jatropha oil is significantly higher as the baseline cost of woodfuel: US$0.73/l or US$19.60/GJ compared to US$1.95/GJ for fuelwood. Jatropha oil being a higher quality energy carrier can be an attractive diesel substitute, both as a blend or as a biofuel in adapted engines, since the observed diesel cost in rural Shinyanga was US$1.49/l. It can be used as a fuel for the production of off-grid electricity at a production cost of US$0.60/kWh. Jatropha oil is further highly economical as an ingredient for Jatropha soap production though, this is a niche market.

In contrast, rotational woodlots have great potential to create revenue for rural smallholders and alleviate household energy scarcity in semi-arid Shinyanga by supplying fuelwood and charcoal well below the present market price. Fuelwood can be produced for US$0.53/GJ and charcoal for US$1.71/GJ, compared to a market farm-gate price of US$4.47/GJ for charcoal. The NPV per hectare of rotational woodlots, relative to maize production in the baseline, can be maximized to US$1,165/ha by selling poles and charcoal while intercropping. Such a configuration also requires the highest labour demand. Return on labour is maximized when producing poles and fuelwood in a monoculture setting (US$6.96/man-day). Thus, a farmer who is constrained by land and wishes to maximize added value per hectare is better off when producing poles and charcoal from an intercropped woodlot, while a farmer with excess of land, but a labour constraint is better of when producing poles and fuelwood from a monoculture woodlot. However, the government license presently needed for commercial wood production from private land is so high that it undermines the economic feasibility of smallholder woodlots.

In the case of carbon forestry and rotational woodlots, the mean annual biomass increment has a large impact on the economic feasibility. The impact of the annual Jatropha seed yield on the production cost of Jatropha oil is less decisive, since 91% of the labour costs are independent of the per hectare seed yield and labour costs make up 71% of the total discounted costs of Jatropha oil production. For all three systems, labour is the largest cost factor, though the labour demand and labour intensity of Jatropha oil production stands out. The shadow cost of labour has a dominant impact on the economic feasibility. The NPV and the cost of energy are highly sensitive towards variations in the shadow cost of labour, especially in the case of Jatropha oil production. However, this rural shadow cost of labour is hard to value in monetary terms and therefore highly uncertain. Because labour is added compared to the baseline of maize production, potential employment is created for all systems. On the other side, a lack of labour availability during the agricultural season can be an obstacle for implementation. In case of rotational woodlots, wood harvesting is carried out during the agricultural off-season, so that labour competition with food production can be avoided.

Appendix A. Field survey in Shinyanga Rural

A small survey was carried out in villages around Shinyanga urban, on November 7th 2007. The results are listed below (Table 1).

Table 1
Data collected during a survey in four villages around Shinyanga urban.

Village	Samuye	Mwamala	Usanda	Old Shinyanga	Remarks
ENERGY					
Price ox-cart of fuelwood (Tsh)	10,000	7,000	10,000		
Price headload of fuelwood (Tsh)	500	Not common	500	500–700	Depending on season
Weight headload of fuelwood (kg)	30		15	13	Samuye probable overrated
Household fuelwood consumption	2 hl[a]/week	4 ox-carts/year	3.5 hl/week	7 headloads/week	1 ox-cart is 20 headloads
Households size	7 persons	7 persons	7 persons	9.5 persons	
Wood surplus/deficit	Deficit	Deficit	Deficit	Deficit	
Fuelwood consumption if surplus	3 hl/week	8 ox-carts/year	7 hl/week	14 headloads/week	
Crop residues use as a fuel	Occasionally	Occasionally	Maize cobs		
Price crop residues (Tsh)	Free	Free	Free		
Cow dung used as fuel	Not common	Never	Not common		
Dominant cooking method	3-stone	3-stone	3-stone	3-stone	
Charcoal price farm-gate (Tsh)	9,000–12,000	7,500	6,000–7,000	7,500–8,000	Illegal bicycle transporter: Tsh 5000 at 25 km from Shinyanga
AGRICULTURE					
Farm-gate price maize (Tsh/debe)	6,000	5,000	5,500		1 debe (bag) is approx. 18 kg
Price of cow manure per ox-cart (Tsh)	10,000	Price not fixed	2,000–3,000		
Price of fodder grass (Tsh)	2,000/sack	Not common	500/bundle		
Land rent agriculture (Tsh/acre/season)	20,000	10,000	20,000		
Land rent grazing land (Tsh/ha/season)	20,000	19,500	18,300		
Other					
Price of poles (Tsh)	1,000–3,000	2,000	2,000–3,000		Mwamala: 3 × Ø 0.15 mtr.
Price of kerosene (Tsh/l)	1,500	1,500	1,800		
Price of diesel (Tsh/l)	1,525	1,525	1,800		

[a] hl = headload.

Table 2
Average fuelwood headload weight as estimated or surveyed by various sources.

Average weigh headload (kg)	Source	Location
14	Survey Appendix A	Shinyanga rural
30	[82] Ngaga	Tanzania
15–25	[83] Minja	Shinyanga
8–16	[9] HASHI	Shinyanga
18.6	[84] MNRT	Mbeya Municipality
14.4	[84] MNRT	Mwanza City
18.6	[84] MNRT	Dodoma City

Table 3
Fuelwood consumption and demand estimate in East Shinyanga. Wood consumption in cubic meters was converted to tonnes assuming an average wood density of 0.80 tonne DM/m^3, based on the species *Acacia polyacantha* and *Acacia nilotica* [70].

Location	Fuelwood consumption (tonneDM/capita/year)	Fuelwood demand (tonne DM/capita/year)	Source
Samuye	0.24	0.36	Survey, see Appendix A
Mwamala	0.18	0.37	
Usanda	0.42	0.83	
Old Shinyanga	1.23	2.46	
Average	0.52	1.00	
East Shinyanga	0.56	1.60	[85] Kaale et al.
West Shinyanga	1.44	1.60	
Assumption	0.55	1.20	

Table 4
Household fuelwood cooking efficiency in Tanzania.

Thermal efficiency	Source
5%	[86] Ishengoma
8–12%	[87] Pesambili
10–18%	[87] MNRT
7–12%	[3] Kaale
5%	[88] Carl Bro Int. (1983) in Johnsen
10%	[89] Kaltschmitt (2001) in Jürgens

Appendix B. Baseline energy consumption

Table 2 indicates various estimates and surveys of the average fuelwood headload size: the value of 30 kg is likely to be exaggerated as an average. The average headload was estimated to weight 16 kg. The energy content of air dry *Acacia nilotica* is 15.9 MJ/kg. From this, the shadow cost of fuelwood is determined to be US$_{2007}$ 1.95/GJ. The annual per capita fuelwood consumption was assumed based on the following data (Table 3).

With an average household size of 6.7 persons [7], the annual household fuelwood consumption and demand is 3.70 tonne and 8.04 tonne, respectively. The efficiency of 3-stone stoves was estimated to be 7%, based on the following data (Table 4).

Table 5
Costs, efficiencies and lifetimes of various cooking stoves and the related cost of energy in terms of utilized heat.

Energy carrier	Stove type	Efficiency	Cost (US$)	Lifetime	Source	Cost of energy (US$/GJ$_H$)
Wood	3-stone stove	7%	Free	–	See Table 4	27.89
	Mud stove	22.5%.	1.43	2 months	[87] Pesambili	9.28
	Burnt brick stove	29%	33.20	5 years	[4,87] Malimbwi et al.; Pesambili	7.22
Charcoal	Traditional stove	16.5%	1.66	3 years	[4,87] Malimbwi et al.; Pesambili	35.21 Tax 21.73 No tax
	Double ceramic liner stove	45%	8.00	3 years	[87] Pesambili	13.02 Tax 8.08 No tax
Kerosene	Kerosene stove	46%	12.45	5 years	[90] Anozie et al.	95.43
Electricity	Electricity stove	68%	49.80	5 years		42.32

Table 6
Energy consumption and demand in East Shinyanga, expressed in GJ.

Energy	Energy consumption (GJ/capita/year)	Energy demand (GJ/capita/year)
Primary energy E_{prim}	8.77	19.13
Utilized heat E_{heat}	0.72	1.56

Characteristics of various cooking stoves are listed below (Table 5).

Bakengesa estimated that 5–10% of the population is using improved cooking stoves [37], which results in an overall estimated average fuelwood cooking efficiency of 8%. The related annual heat consumption is shown in Table 9 (Table 6).

Appendix C. Maize production in East Shinyanga

The opportunity cost of land is based on the average renting price in rural Shinyangan (Table 7).

Table 8 shows the average maize production in Shinyanga over the period 1997–2003. As can be seen in Table 8, maize production is fluctuating significantly per season, depending on the annual rainfall. Therefore, a time series of annual maize production is needed to estimate the average yield. However, the national statistics of Table 8 include Kahama and Bukombe district, which are in West Shinyanga and receive significantly more annual rainfall compared to East Shinyanga.

Table 9 shows maize production estimations in Shinyanga per district in 2006, based on field assessment. As can be seen in Table 9, average maize yields are a factor 0.83 lower for the eastern districts as for the whole of Shinyanga. Applying this factor on the average production of Table 8 results in an average maize production of 0.77 tonne/ha for East Shinyanga. However, this number is highly uncertain since there is no time series of maize production per district in Shinyanga available. Therefore, more literature was collected, as shown in Table 10. Again, the maize yield data shows large variations. Considering the above data, an average maize production of 0.80 tonne/ha for East Shinyanga was estimated. The average maize market price was estimated to be Tsh 4,500/debe (US$207.50/tonne), based on various sources, as shown in Table 11.

The shadow cost of labour and the return on labour of maize production in East Shinyanga were estimated using formulas (1) and (2), based on the data as presented in Table 12. The labour intensity of maize cultivation was determined by taking averages of the studies used to determine the shadow cost of labour (see Table 13).

Table 7
Average renting price of land for agricultural and grazing purposes in rural Shinyanga.

Village	District	Renting cost of land (US$/ha/season)		Source
		Agriculture $C_{land,agro}$	Grazing $C_{land,gr}$	
Samuye	Shinyanga rural	41.02	16.60	Survey Appendix A
Mwamala	Shinyanga rural	20.51	16.19	"
Usanda	Shinyanga rural	41.02	15.19	"
Mwamnemha	Bariadi	29.53	–	[19] Monela et al.
Buzinza	Kishapu	36.92	–	[91] Msuya et al.
AVERAGE	33.80	15.99		

Table 8
Maize production in Shinyanga. Source: MAFC [92].

Year of harvesting	Land under maize cultivation (ha)	Maize production (tonne)	Maize production (tonne/ha)
1997	181,300	243,600	1.34
1998	269,100	269,100	1.00
1999	211,700	103,800	0.49
2000	211,700	169,400	0.80
2001	134,000	201,000	1.50
2002	341,800	346,900	1.01
2003	313,900	117,200	0.37
Average			0.93

Table 9
Estimated maize yield in Shinyanga districts in 2006, based on field assessment. Source: Shinyanga regional government, department of agriculture [33].

District	Area (ha)	Yield (tonne)	Productivity (tonne/ha)
Shinyanga urban	2,342	2,342	1.00
Shinyanga rural	63,800	44,680	0.70
Kishapu	15,778	11,045	0.70
Maswa	48,921	34,244	0.70
Bariadi	65,000	97,500	1.50
Meatu	31,826	25,460	0.80
Total East Shinyanga	227,667	215,271	0.95
Kahama	116,993	116,993	1.00
Bukombe	69,200	138,400	2.00
Total Shinyanga	413,860	470,664	1.14
Factor difference eastern districts and whole of Shinyanga			0.83

Table 10
Average maize yield estimations and maize yields at maize research plots in Shinyanga region.

Average maize yield (tonne/ha)	Source	Remarks
0.80	[93] Mungroop et al.	Meatu district, Shinyanga
1.30	[94] Shinyanga District Council	Year 2004
1.00	[94] Shinyanga District Council	Year 2005
0.75	[75] Mdadila (1998) in Limbu	Average for Shinyanga region
0.80	[75] Van der Linde et al. (1998) in Limbu	Average for Lake Zone, poorest conditions
Maize test plots (tonne/ha)		
1.33	[9] HASHI	Year 1994
1.64	[9] HASHI	Year 1995
0.85	[9] HASHI	Year 1996
0.56	[95] HASHI	Year not known

Table 11
The market price of maize in East Shinyanga by different sources.

Maize price (Tsh/debe)	Maize price (US$/tonne)	Source
6,000	276.67	Survey data, see Appendix A
5,000	230.56	
5,500	253.61	
4,500–5,000	207.50–230.56	Shinyanga regional government, department of agriculture, prices October 2007 [33]
3,500–5,000	161.39–230.56	Shinyanga Rural District Government, annual price variation [28]

Table 12
Estimate of the Return on labour and the Shadow cost of labour.

Study	Management Costs (US$/ha)	Labour input (man-days)	Return on labour (US$/man-day)	Shadow cost labour (US$/man-day)
[75] Mdadila	61.73	74	1.41	0.95
[75] Van der Linde et al., 1998, Hand hoe	9.39	90	1.74	1.36
[75] Van der Linde et al., 1998, Ox ploughing	29.90	60	2.27	1.71
[12] Ramadhani et al.	71.64	44.5	2.12	1.36
Other estimates shadow cost of labour of land worker				
0.5 $\times$ official minimum wage rate (Monela, 1989 in Kihiyo [11]				1.53
Tsh 2,000/man-day [37]				1.66
Shadow cost of collecting various woodland products: Tsh 1,768/man-day [19]				1.47
Average			1.88	1.43

Table 13
Labour intensity of maize cultivation in Tanzania.

Parameter	[75] Mdadila (1998) in Limbu	[75] Van der Linde et al. (1998) in Limbu	[12] Ramadhani et al.	Average
Land preparation by hand hoe	28	40	14.6	27.5
Maize sowing	1	6	4.3	3.8
Weeding	26	20	16	20.7
Maize harvesting	10	10	12.1	15.8
Threshing		9	6.3	

Appendix D. Input data

Tables 14 and 15.

Table 14
Input data for the cost/benefit analysis.

Parameter	Data[a]	Unit	Source	Remarks
Baseline				
Discount rate	16.4%		[56] Bank of Tanzania, 2008	Average 12-2004–4-2007
Inflation rate	4.6%		[56] Bank of Tanzania, 2008	Average 2002–2006
Renting cost arable land	33.80	US$/ha/year	See Appendix C	
Renting cost grazing land	15.99	US$/ha/year	See Appendix C	
Fuelwood consumption	0.55	Tonne/cap/year	See Appendix B	
Fuelwood demand	1.20	Tonne/cap/year	See Appendix B	
Fuelwood price	600	Tsh/headload	See Appendix A	
Average headload weight	16	Kg/headload	See Appendix B	
Energy content wood	19.8	MJ/kg oven dry	[57] Bryce	*Acacia nilotica*
Moisture content wood	12%	Air dry	[57] Bryce	*Acacia nilotica*
Energy content charcoal	32	MJ/kg	[1] Rosillo-Calle et al.	
Average cooking efficiency	8%		See Appendix B	
Charcoal price	5,000	Tsh/bag	See Appendix A	
Average weight of bag	29	kg/bag	Measured	
Government registration fee woodfuel production	200,000	Tsh/year	[10] Maganga	Both public and private land
Payable fee fuelwood	4,000	Tsh/ox-cart	[10] Maganga	Counted as 1 m^3
Payable fee charcoal	2,000	Tsh/bag	[10] Maganga	
Payable fee poles	2,000	Tsh/pole	[10] Maganga	$Ø > 0.10$ m
Reduction payable fee	80%		[10] Maganga	From private land
Price of electricity	106	Tsh/kWh	[58] Semsella	
Off-grid connection fee	246,000	Tsh/hh	[58] Semsella	
Payback time connection	10	Years		Assumption
Service charge	1,892	Tsh/month	[58] Semsella	
Market price of kerosene	1.25	US$/l	See Appendix A	
Carbon forestry				
Mean Annual Increment	2	Tonne/ha/year	Estimate[b]	
Max. biomass stock	50	Tonne DM/ha	[61] Mabugu et al.	See above
Root-to-shoot-ratio	0.40		[62] IPCC	For tropical shrubland
CER price	16.55	Euro	www.carbonpositive.net	Sec. market price 03-2008
Credit buyer discount rate	4.75%		www.carbonpositive.net	See below[c]
Crediting period	30	Years	[52] Neeff et al.	
CER issuance fee	0.10	US$/CER	[52] Neeff et al.	
Adaptation levy	2%	Of CERs	[52] Neeff et al.	
Project development	30,000	US$	Estimate[d]	
Validation	25,000	US$	[63] SGS	In year 0
Monitoring	8,081	€$_{2006}$	[54] Zahabu	In year 5
	5,040	€$_{2006}$	[54] Zahabu	In year 10, 15, 20, 25

Table 14 (*Continued*)

Parameter	Data[a]	Unit	Source	Remarks
Verification and monitoring	15,000	US$	[63] SGS	In year 5
	7,500	US$	[63] SGS	In year 10, 15, 20, 25
VER price	10	€	[64] FACE	
Forest buffer size	25%		[53] SGS	For risk mitigation
Project development Voluntary market	25,000	US$	Estimate	See below[e]
Bank fee	2.5%	Of turnover	[64] FACE	Triodos CCH fee
Annual land lease fee	1	US$/ha/year	[55] TRA	
Tree density	400	Trees/ha	[34] Rubanza	Spacing 5×5 m
Spotplanting	12	min/tree	[10] Maganga	See below[f]
Spotweeding	3	min/tree	Estimate	$2 \times$ per year in year 1–3
Slashing using tractor	0.5	md/ha	Estimate	$2 \times$ per year in year 1–3
Fireline maintenance	0.5	md/ha/year	Estimate	
Wage rate	3,687	Tsh/md	[65] Morogoro	
Project manager	600,000	Tsh/month	[66] Mwamhanga	
Secretary	200,000	Tsh/month	[66] Mwamhanga	
Forester	300,000	Tsh/month	[66] Mwamhanga	2 foresters assumed
Non-wage labour cost	16%		www.doingbusiness.org	Tanzania page
Office expenses	4,917	US$/year	[67] MNRT	
Tractor and harrow	40,971	US$	[67] MNRT	See below[g]
Overhead costs project	13%		[69] Bretton Woods	World Bank Carbon Fund
Land lease registration fee	220,000	Tsh	www.doingbusiness.org	Tanzania page
Cost of seedlings	60	Tsh_{1996}/piece	[67] MNRT	
Cost of planting tools	5,682	Tsh_{1996}/ha	[67] MNRT	Converted for tree spacing
Cost of manure	1,969	Tsh/tonne	Estimate	See below[h]
Water supply	9,833	US$	[67] MNRT	
Pick-up truck	32,777	US$	[67] MNRT	
Office renovation	8,194	US$	[67] MNRT	
Office equipment	3,933	US$	[67] MNRT	
Manure application	2,5	kg/seedling	[34] Rubanza	When planting
Lifetime equipment	30	Years	Assumption	
O&M tractors and truck	3%	Per year	Assumption	Of investment cost
Diesel cost	1,500	Tsh/l	Observed	Shinyanga urban
Diesel cost slashing	6,000	Tsh/ha	Estimate	1 l/km
Diesel cost fireline maintanance	600	Tsh/ha	Estimate	
Fuelwood collecting by ox-cart	20	Headloads/md	Estimate	20 headloads $\approx$ 1 ox-cart
1st year of wood yield	7	Year	Assumption	
Fuelwood production	10%		Assumption	of MAI, after year 7
Rotational woodlots				
Project lifetime	21	Years		3 rotations first stratum
Rotation period	7	Years	[39] Nyadzi et al.	
Wood harvest	70.9	Tonne dm/ha	[39] Nyadzi et al.	
Tree density	833	Trees/ha	[39] Nyadzi et al.	Spacing 3×4 m
Energy content *Acacia polyacantha*	19.8	MJ/kg oven dry wood	Assumption	Equal to *Acacia nilotica*
Wood density *Acacia polyacantha*	0.78	Tonne DM/m^3	[70] ICRAF	0.72–0.84 tonne/m^3
Biomass Expansion Factor	1.23		[71] HASHI	6-year-old *A. polyacantha*
Annual vegetation growth	2	Tonne DM/ha/year	[34] Rubanza	1.5–2.5 tonne DM/ha/year
Vegetation growth woodlot	40%		[9] HASHI	*A. polyacantha* in year 4
Charcoal kiln efficiency	30%	Weight basis	[72] Malimbwi	Best practise
Price of poles	39	US$/tonne		See below[i]
Stem wood for poles	40%		Estimate	Of total wood
Cost of seedlings	150	Tsh/seedling	[10] Maganga	100–200 Tsh/seedling
Tree planting tilted land	88	Trees/md	[12] Ramadhani et al.	Tilted for maize cultivation
Slashing by hand	8	md/ha	[67] MNRT	$2\times$/year, years 1–3
Fireline maintenance	10	md/ha	[67] MNRT	Each year by hand
Tree cutting	0.38	md/tonne	[12] Ramadhani et al.	Dry matter wood
Wood chopping	1.46	md/tonne	See below[j]	Dry matter
Kiln preparation	6.7	md/tonne	[4] Malimbwi et al.	
Carbonization	9.3	md/tonne	[4] Malimbwi et al.	Per tonne charcoal
Unloading kiln	2.7	md/tonne	[4] Malimbwi et al.	Per tonne charcoal
Manure application	2	md/ha	Estimate	Based on [12]
Maize yield	0.80	Tonne/ha	See Appendix C	See below[k]
Manure application	2.5	Kg/seedling	[34] Rubanza	Only for planting
Cost of maize seed	2,500	Tsh_{1998}/ha	[75] Van der Linde et al., (1998) in Limbu	
Jatropha oil production				
Project lifetime	21	Years		
Jatropha seed yield	2	Kg/shrub	Estimate[l]	From year 9 and onwards[m]
Shrub density monoculture	1,600	Shrubs/ha	[49] Mshanga	Spacing 2.5×2.5 m
Shrub density intercropping	1,333	Shrubs/ha	[49] Mshanga	Spacing 2.5×3 m
Oil content Jatropha seeds	38%		[76] Pant et al.	On higher altitude
Seed weight	46%	Of total fruit	[15] Openshaw	
Jatropha oil density	0.92	Kg/l	[15] Openshaw	
Jatropha oil energy content	40.7	MJ/kg LHV	[15] Openshaw	
Oil extraction rate press	62.5%		[16] Henning	60–65%
Farm-gate price seeds	100	Tsh/kg	[77] Van Eijck	Produced in Shinyanga
Cost of raising seedlings	100	Tsh/seedling	Estimate	See below[n]
Pay-back period seedlings	10	Years	Assumption	

Table 14 (*Continued*)

Parameter	Data[a]	Unit	Source	Remarks
Intercropping years	5	Years	[49] Mshanga	From establishment
Annual manure application	1	Kg/shrub/year	[49] Mshanga	
Seedcake/cow manure equiv.	3.9	Kg/kg	[18] Van Eijck	Based on N-rate
Pruning years	4,8,12		[49] Mshanga	Every 4 years
Pruning	2	min/shrub	Estimate	
Manure application	2	md/ha	Estimate	
Seed harvesting	40	md/tonne	See below[o]	
Oil pressing and filtering	1.5	hour/l oil	[78] Henning	
Cost of vessel	15,000	Tsh	Observed	250 l
Cost of ram press	220,000	Tsh	[49] Mshanga	
Lifetime of ram press	5	Years	[16] Henning	
Cost of plant oil stove	40	Euro	[46] Kratzeisen et al.	
Efficiency plant oil stove	45%		[79] BHS	40–50%
Lifetime plant oil stove	5	Years	Estimate	
Cost of generator	184	US$/kW	Observed	
Generator efficiency	27%		[8] Ilskog et al.	
Generator adaptation	830	US$	[77] Van Eijck	
Primary electricity cable	11,181	Tsh/m	[58] Semsella	
Secondary cable, installation and meter	246,000	Tsh/hh	[58] Semsella	Assumed to be equal to TANESCO rate
Electricity cable length	10	m/hh	Assumption	Length needed per house
Light point	9,125	Tsh/hh	[58] Semsella	
Socket	13,960	Tsh/hh	[58] Semsella	
CFL lamp, 15 W	7,000	Tsh/hh	[58] Semsella	
Electricity demand	35	kWh/month	[8] Ilskog et al.	Per household
Peak demand	1,000	W/hh	Assumption	
Annual O and M	4%		Assumption	Of investments
Lifetime investments	10	Years	Assumption	
Diesel price	1,800	Tsh/l	See Appendix A	In rural Shinyanga
Government levy	200	Tsh/l	[55] TRA	
Road toll	100	Tsh/l	[55] TRA	
Value Added Tax	20%		[55] TRA	
Transesterification cost	0.25	US$/l	Assumption	Including transport
Price soap farm-gate	500	Tsh/piece	[80] Matchmaker	90 g per piece
Jatropha oil needed	0.56	l/kg soap	[16] Henning	
Weight of soap per piece	90	Gram	[80] Matchmaker	
Energy cost	300	Tsh/l oil	[80] Matchmaker	
Caustic soda needed	0.083	Kg/kg soap	[16] Henning	
Cost of caustic soda	700	Tsh/kg	[80] Matchmaker	
Packaging	160	Tsh/kg soap	[16] Henning	
Labour intensity soap	0.74	Man-hour/kg	[16] Henning	

[a] Monetary values are expressed in US$$_{2007}$. Historical monetary values in Tanzanian Shelling (Tsh) were first corrected to 2007 values using a Consumer Price Index [59], before being converted to US Dollars using the average currency conversion rate over 2007 (1 US$ = Tsh 1,205) [60].

[b] Based on an estimate made by Mabugu et al., who indicated a default biomass stock of 50 tonne DM/ha for mature dry woodlands in Zimbabwe [61]. We assumed 25 years of growth, which leads to a mean annual above-ground biomass increment (MAI) of 2 tonne DM/ha/year. Malimbwi et al. determined a similar MAI for Miombo woodlands in Tanzania [4].

[c] Determined indirectly: CER price 07-2007 = € 14.50, tCER price 07-2007 = € 3.00 (Carbonpositive.net). Input in formula 10, using a crediting period of 5 years, yields a discount rate of 4.75%.

[d] Based on: World Bank [68]; Locatelli et al. [13]; Cacho et al. [14].

[e] The Project Design Document (PDD) does not have to be according to CDM standards. Furthermore, time is saved because the CDM procedure is rather time consuming [64].

[f] Labour cost is 15,000 Tsh/acre, divided by assumed shadow labour cost of US$1.43 per man-day.

[g] The number of tractors needed depends on the woodland size. The labour intensity for slashing by tractor is estimated to be 1 man-day/ha/year and for fireline maintenance 0.5 man-days/ha/year.

[h] Average of prices mentioned in survey (Appendix A) and by Bakengesa (12,500 Tsh$_{2007}$/ox-cart) [37], using a weight of 0.35 tonne manure per ox-cart [34].

[i] Average of Tsh$_{2007}$ 2,000 for pole 3 × Ø 0.15 m (=US$$_{2007}$ 40.18/tonne wood) (Appendix A) and Tsh$_{1996}$ 18,000/m^3 for poles (=US$$_{2007}$ 37.40/tonne wood) [67].

[j] Average of 1.28 man-days/tonne [12] and 1.65 man-days/tonne. The latter is based on 13 man-days per 1.5 tonne charcoal at a kiln efficiency of 19% (average in Tanzania) [4].

[k] Intercropping maize yield: year 1: 100%, year 2: 70%, year 8,15: 200%, year 9,16: 125%. Based on Nyadzi et al. [39].

[l] Based on Mshanga [49] and Van Eijck [75].

[m] 0.5 kg in year 3, 1 kg in years 4–5, 1,5 kg in years 6–8.

[n] Based on a market price of 100–200 Tsh/seedling for Acacia seedlings [10].

[o] Based on Henning [78]: 3 kg seed/hour, which is 41.7 man-days/tonne, and Van Eijck [18]: 33–40 man/days/tonne seed.

Table 15
Uncertainty ranges for main input parameters (see paragraph 3 for references).

Parameter	Unit	Base case	Max		Min	
Shadow cost of labour	US$/man-day	1.43	3.06	(114%)	1.00	(30%)
Real discount rate	–	11.8%	17.9%	(51%)	6.8%	(42%)
Headload of fuelwood cost	Tsh/headload	600	800	(33%)	400	(33%)
Bag of charcoal cost	Tsh/bag	5,000	9,000	(180%)	5,000	–
MAI Carbon forest	Tonne DM/ha/year	2	3	(50%)	1	(50%)
CER/VER market price	Euro	16.55/10.00	+25%	–	−25%	–
MAI woodlot	Tonne DM/ha/year	10.13	12	(18%)	5	(51%)
Kiln efficiency	–	30%	30%	–	10%	(67%)
Max. Jatropha seed yield	Kg/shrub/year	2	1	(50%)	3	(50%)
Jatropha plantation size	Hectare	1	3	(200%)	0.41	(59%)

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